Chapter 7

Conclusion

7.1 Summary of Achievements

The goal of this thesis was to develop algorithms for restoring MR images reconstructed from data corrupted by patient motion during the scan time. The rotational model of the motion was selected because the translational model has already been studied in depth, as reported in past literature. Therefore, this thesis can be regarded as an extension of the motion models developed in the past [142]. Rotational motion being a primary component of gross in-plane movements, inclusion of such motion into the existing translational model, accurately describes patient movements involving head and limbs. As described in Chapter 1, motion artifacts arise from both intra-view and inter-view effects. Gradient moment nulling techniques are effective against intra-view effects. However, a similar general method for suppressing inter-view effects is not available at present. This is evident from the vast range of techniques available for reducing specific types of inter-view effects, such as respiratory and cardiac movements as well as voluntary patient movements involving translations, rotations and expansions. Many of these techniques are reviewed in Chapter 1.

One of the significant contributions of this thesis is the development of a method for extracting the ROI from the motion affected MR image, described in Chapter 2. An accurate estimate for ROI is shown to be useful both in motion estimation and in POCS based data estimation.

The affect on the acquired MR data in the k-space due to in-plane rotations around any axis parallel to the slice selection direction, is analyzed in Chapter 3. It is shown that in order to restore the image analytically, constraints on the type of rotational motion have to be imposed, so that the rotations at each view can be modelled using a minimum number of parameters. Two examples including single step rotation, and rotation at constant angular velocity, are described in Chapter 3.

A more general technique of rotational motion parameter estimation is provided in Chapter 4. Therefore, the constraints on the type of rotation are removed. An added advantage of this method is that it is capable of estimating the rotation angle associated with each view in the midst of concurrent translational motion. Due to the transformation of the estimation problem from one N-dimensional minimization to N single-dimensional minimizations, the estimation speed is greatly enhanced while reducing the computational complexity. The motion parameter estimation from the corrupted data themselves is widely regarded as a difficult task even for pure translational movements. With the added complexity of rotational movements, such estimations were highly time consuming in the past. The new method proposed in this thesis provides a new perspective to this problem and a solution which is both effective and easy to implement.

It is shown in Chapters 4 and 5 that gross in-plane rotations cause data overlaps and voids in the corrected k-space data. The weighted averaging method presented in Chapter 5 has been shown to be effective in managing the overlap data which minimizes the interpolation errors and data corruption due to noise. An iterative algorithm based on POCS was developed to estimate the missing data within data void regions. Constraints based on the finite support and consistency with the collected data are used to form the convex sets in POCS. In spite of the effective removal of motion artifacts, the usefulness of the iterative method is marred by the necessity for computing a highly complex regularization error metric for the purpose of termination of iterations. This limitation is overcome using the fuzzy POCS algorithm described in Chapter 6.

7.2 Suggestions for Further Research

Despite the existence of a plethora of post-processing artifact correction techniques, none is chosen for widespread use in clinical settings. A major reason being the inadequacy of the established motion models in representing realistic movements. However, the expectation of a globally valid mathematical model is also viewed as unrealistic. Therefore, the perspective of this and on-going research is to develop models that can effectively and efficiently suppress motion artifacts due a particular type of motion. Such an array of models may be then combined to develop a generalized technique, which warrant the user to choose appropriate combination of models. It is also envisaged that automatic selection of motion models may be possible in the future.

Most post-processing techniques, including the one presented in this thesis are restricted to the correction of motion in the imaging plane. Although there are a handful of out-of-plane translational motion correction techniques [53][54][76][77], the model used in these algorithms is oversimplified and does not include the anatomical information embedded in the adjacent slices. In the future, 3-dimensional techniques will need to be used for effective motion models for out-of-plane motion.

Further work is required to develop algorithms that are capable of suppressing artifacts due to multiple and independent motion of imaged objects. This causes the motion to become dependent upon position as well as time. Since it is unlikely that motion of the internal organs can be measured with adequate accuracy, motion estimation from the k-space data will be required, although the corruption of the data becomes further complicated due to such independent movements. Inevitably, appropriate simplifications to the mathematical models need to be devised to enable the image restoration.

The ability of simplified models to represent realistic motion, needs to be investigated using clinical studies in realisting settings. However, further work will have to be undertaken on motion models such as expansion, before embarking on a full scale clinical study, which incurs a large capital cost.

From a more theoretical point of view, the fuzzy POCS algorithm developed in this thesis may find its uses in many other applications in signal estimation and reconstruction. Further theoretical development and application of fuzzy POCS is to be encouraged for future research.